

# Availability and Utilisation of Agricultural and Agro-industrial Wastes\*

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R. W. Detroy and C. W. Hesseltine\*\*

Wastes from agriculture and agro-industries are the excesses and residues from growing and processing raw agricultural products such as grain, fruits, poultry, fish and trees. With the development of intensive production methods for crops and animals, considerable attention has been drawn to the problems of agricultural and agro-industrial waste management. The primary focus of this presentation will be identification of agricultural residues: availability, amount and bioconversion. Residue composition will be of paramount importance, ie, carbohydrates, cellulose, lignocellulose, hemicellulose and starch content. The bioconversion of selected agricultural residues will be explored, as well as the technology for production of single cell protein, methane, organic chemicals and other bioproducts. For economic and technological reasons, primary consideration will be given to the following residues as agricultural resources: animal waste, cellulose, cereal starch and crop residues. Expectations and limitations of agricultural residue bioconversion will be discussed.

## Introduction

This overview concerns mainly the potential utilisation of residues from agriculture and agro-industry, primarily the availability, amounts, and characteristics. Residues are the excesses and wastes from growing and processing of raw agricultural products. Significant amounts are generated each year. The present and potential supply of US agricultural byproducts from domestic crops is not known; however, realistically, the annual total certainly would exceed 500 million tons (dry basis). The feasibility of residue utilisation for energy or chemical production depends on a myriad of residue characteristics: availability, supply, current usage, values of the residue as a useful byproduct or raw material for other products, and the economics of residue collection and storage. It is important to consider residues as resources, not as wastes.

Residue utilisation deserves optimistic consideration because of the large quantities of wastes that are generated and the successful utilisation that has been achieved to date. However, the definition of residues as important resources will require definite incentives such as increasing costs of existing raw materials, maintenance of a quality environment, raw material availability, and need to produce a useful endproduct.

## Past review information on agricultural residues

An accurate, comprehensive analysis of the characteristics of most agro-residues is not available; however, recent publications identify the properties of a number of important agricultural and agro-industrial wastes<sup>1, 2, 10, 12</sup>. Comprehensive studies on utilisation of animal products and on animal waste management by Man<sup>13</sup> and Loehr<sup>11</sup> discuss research conducted in the sixties and seventies. An overview by Sloneker<sup>19, 20</sup> on crop residues and animal wastes defines the availability of these resources in the United

States. Other reviews<sup>2, 10, 12</sup> are mainly concerned with either chemical or microbiological conversion of available agro-residues to useful byproducts, ie, feed supplements, methane, biopolymers, and chemical feedstocks.

## Residue identification

Identification of residues—especially characteristics, generation, and utilisation technology—is thoroughly discussed in the Food and Agriculture Organisation of the United Nations Symposium, Management of Agricultural and Agro-Industrial Wastes<sup>12</sup>. Church<sup>4</sup> and Laskin<sup>10</sup> discuss in great detail the utilisation of available agro-residues by bioconversion to single cell protein.

Identification from broad commodity areas of promising utilisable residues depends upon numerous factors. Fruits and vegetables comprise an enormous commodity area, the processing of which produces the following

residues: seeds, cores, peels, husks, leaves, rejected whole fruit, and juice. These residues occur in all geographical regions, mainly during canning and bottling, and are amenable to composting or fermentation technology. Tables 1 and 2 depict a broad range of agricultural commodities and residues produced annually from harvesting or processing, and their potential utility.

## Availability and utilisation

The potential annual supply of US cellulosic byproducts from domestic crops is certainly in excess of 500 million tons (dry weight). In general, cereals produce some 2 pounds of straw/pound of grain harvested. Conversion of this quantity of organic matter to useful products would double US agricultural output with essentially little increase in input energy. Significant accumulations of major crop residues are, of course, confined to those areas of intensive

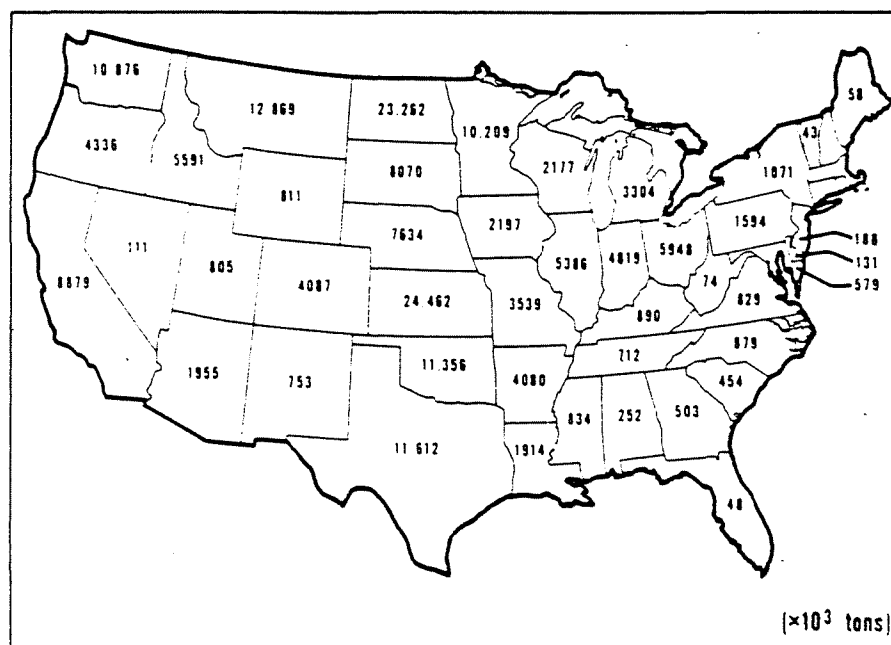


Figure 1. Geographical distribution of cereal straws (flax, wheat, rye, rice, oats, barley).

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\*\* R. W. Detroy and C. W. Hesseltine are at the Northern Regional Research Centre, Agricultural Research Service, US Department of Agriculture, Peoria, Illinois 61604.

Table 1. Residues from the Processing and Harvesting of Major Agricultural Commodities

Commodity	Residues	Potential Utilisation
Wheat, rice, barley, oat Corn	Straw Stalks, husks, cobs	Animal feedstuff, fuel, silica, furfural Animal feedstuff, fuel, chemical hydrolysis, compost, silage, fermentation
<i>Processed grains</i> Corn (wet-milling)	Wastewater	Utilisation of CHO waste, single cell protein, reduce BOD
(dry-milling)	Wastewater	
Wheat	Bran	Animal feeds
Rice	Rice bran	Oil, vitamins
Soybean	Soy waste	Single cell protein
<i>Other commodities</i> Cattle, swine	Animal waste	Refeeding, fermentation-feed supplement, CH <sub>4</sub>
Sugarcane, other sugar products	Bagasse	Fuel, animal feed <i>via</i> fermentation, alcohol, sugar byproducts
Wood pulp	Sulphite liquor	Single cell protein

cropping. The general distribution of potentially collectable cereal straws in the United States is depicted in Figure 1. All crops produce collectable residues; however, the distribution of straw residues increases the costs of utilisation. These collectable residues from major and minor crops are depicted in Tables 3 and 4. The residues produced by the majority of these crops are left in the fields. Only with sugarcane, vegetables, fruit, and peanuts are there significant accumulations at specific processing sites.

Since the quantity of straw produced is equal to or greater than the quantity of edible grain from cereal crops, its utilisation is of paramount importance. Present constraints on the utilisation of cereal byproducts include: new technology development, residue collection, marketability, practical utility of residues, and research on model bioconversions. Collection costs of important residue resources govern the economic feasibility of the chemical or bioconversion process.

Mechanical equipment exists for harvesting corn refuse, silage, or hay and can readily be used for the collection and hauling

of plant residues to central locations for processing. Sloneker<sup>19</sup>, in a recent review, discusses types of harvesting operations which can be employed to stack, bail, windrow, chop, and transport various crop residues. Time and expensive equipment are serious deterrents to collection of crop refuse in on-the-farm operations. Any major increase in the use of cereal straws and other residues will require major efforts to collect, handle, transport, and deliver at a central location or plant so that they will be competitive with other raw materials. Benefits from mass collection of straw residue must be balanced against the consequences of its removal from fertile crop land. No doubt residues ploughed under or left on the surface (conservation tillage) increase the tilth of the soil, aid in H<sub>2</sub>O sorption, and reduce soil erosion; therefore, the impact that continuous residue removal will have on soil fertility must be thoroughly examined. However, refractory material that remains after bioconversion of agro-residues may, if returned to the land, provide sufficient material for tilth and organic matter in the soil.

The wet-milling process of cereal grains

produces considerable quantities of grain carbohydrate waste. The waste-liquid streams that arise as a result of steeping, corn washing, grinding, and fractionation of corn contain corn starch, corn syrup, gluten, and corn steep liquor. Studies<sup>4</sup> have been conducted on the bioconversion of these negative-value carbohydrate waste into animal feed protein-vitamin supplements as well as on economical pretreatment of the industrial waste being produced.

Church and coworkers<sup>4</sup> have described a pilot fermenter process for bioconversion of corn milling waste waters using fungi, *Gliocladium deliquescens* and *Trichoderma viride*. The pilot fermentation ran continuously for 4- and 5-month periods with BOD reductions ranging between 93-98%, fungal mycelia containing 42-46% protein, and a minimum of operational difficulties. Table 5 depicts a typical biodegradation of corn wet-milling waste by *G. deliquescens*<sup>4</sup>. Carbohydrate and BOD levels in the waste feed were reduced 93 and 98%, respectively. Animal-feeding studies with mice, rats, chickens, and weanling hogs were successful in terms of weight gain and litter size. A summary of waste characteristics from grain processing is depicted in Table 6. No process waste waters are produced by the milling of wheat and rice grains. However, the bran from these two cereals contains 5-10% oil and is rich in certain 8 vitamins and amino acids. The oil from rice bran can be utilised as an edible oil after refining and in the manufacture of soap.

Church and coworkers<sup>4</sup> have also reported on bioconversion of food-processing wastes with fungi, especially *T. viride* and *G. deliquescens*. Studies were conducted on corn- and soy-canning wastes in a vessel containing 11,000 gallons. Continuous culture digestion of corn wastes by *T. viride* is shown in Table 7. BOD, COD, and carbohydrate levels were reduced 96.2 to 99.2%. The fungal mycelium was an excellent feed for weanling rats. Soy waste was also an excellent carbohydrate-nitrogen source for the propagation of the two fungi.

A potential resource of the immense US animal industry is the annual generation of over 2 billion tons of waste. Recent changes in the fertiliser and animal-feeding industries have caused the accumulation of animal wastes into localised areas. This localisation has produced air and water pollution problems, not to mention disposal problems. Technological changes in large-volume cattle feeding has created a serious need for new waste technology, either through cost reductions in handling to eliminate pollution hazards or some type of conversion process to a useful endproduct.

The utilisation of animal wastes, other than land usage, as a waste management alternative, has proceeded in two main areas: biological and thermochemical. Major experimentation has involved biogas formation, single cell protein production, and microbial fermentation and refeeding. Animal wastes are excellent nutrient sources for microbial development. Major constituents are organic nitrogen (14-30% protein), carbohydrate (30-50%, essentially all cellulose and hemicellulose), lignin (5-12%), and inorganic salts (10-25%).

In most biological processes, microorganisms consume nutrients present in the wastes to increase their own biomass and, through substrate utilisation, release various

Table 2. Processing Residues from Agricultural Commodities

Commodity	Residues	Potential Utilisation
Fruits and vegetables	Seeds, peels, cones, husks, stones, rejected whole fruit, and juice	Animal and fish feeding, fuel, composting, fermentation
Potatoes	Starch wastewater trimmings, peels	Cattle feed, single cell protein, sugar, biogas, alcohol
Oils and oilseeds: groundnuts, cottonseed, soybean, palm coconut, etc	Shells, husks, lint, fibre, sludge, presscake, wastewater	Animal feedings, fertiliser, fuel, activated carbon, products of pentosans, lignin, furfural, xylitol, protein
<i>Beverage Processing</i> Molasses	Spent molasses liquor stillage	Fermentation chemicals
Coffee	Grounds	Single cell protein, alkaloids

gases and other simple carbohydrate materials. There are mainly two classes of biological processes: (1) biogas, or an anaerobic fermentation; and (2) biochemical hydrolysis. The biochemical processes produce primarily protein, sugar, and alcohol; whereas the anaerobic fermentation takes place under an oxygen-deficient environment to produce methane.

The thermochemical processes involve hydrolysis and hydrocarbonation and yield char (solid), oil, and gaseous fuels.

All of these processes have been successfully demonstrated for livestock manure<sup>2</sup>; however, the greatest handicap thermochemically is the large amount of moisture that needs to be removed to be feasible. The various process alternatives for the generation of renewal fuels from animal manure is depicted in Figure 2. Total production of manure in the United States, according to classes of animals and relative concentrations to the total, are shown in Table 3.<sup>9, 24</sup>

The use of animal waste, primarily as a nitrogen source, in the feeding or refeeding of livestock has been reviewed by Anthony<sup>1</sup> and Smith<sup>21</sup>. In contrast to direct refeeding, feedlot waste (FLW) has been ensiled with hay; and the mixture, when fed to cattle, yielded satisfactory weight gains. Screening of FLW yields a liquid fraction (70% N). Rhodes and coworkers<sup>14</sup> have described a solid-substrate fermentation system that combined FLW liquid (FLWL) with corn. This restrictive environment promotes the growth of certain indigenous microbes while restricting others. The process is a lactic acid fermentation which causes a loss of fetid odour and enteric bacteria and is acceptable to cattle. Hrubant<sup>4</sup> has described the microbial flora of such a process. The silage-like fermentation was dominated by lactobacilli and yeasts. The acid production killed coliforms and other organisms in the FLW. This process conserves most of the nitrogen while converting the waste to a feed with a more desirable amino acid composition. Potential pollutant and health hazards inherent in the waste were reduced by this lactic fermentation. Increased yeast protein synthesis is anticipated with additional inorganic nitrogen.

The utilisation of sugarcane bagasse must be considered on a country-by-country basis. Bagasse is the fibrous residue obtained after the extraction by crushing of sugarcane stalks. This roller-mill process removes 95% of the sucrose, producing a residue which contains some 50% moisture and consists of 15% lignin and 75% cellulose. Annual world production of bagasse is greater than 100 million tons. Bagasse has been used mainly as a fuel in sugarcane factories, for production of pulp and paper, and for structural materials. It has been used to a limited extent as a soil conditioner and cattle feed supplement. Extensive research has been conducted in the past few years on bagasse as a cellulosic raw material for single cell protein production<sup>10, 23</sup>. Cellulosic wastes, such as bagasse, have also received considerable attention as resource material for chemical processes and energy conversions (anaerobic fermentation to methane or ethanol).

The largest wastes from dairy food plants are whey from cheese production and pasteurisation water. A pound of cheese produces 5-10 pounds of fluid whey with a

**Table 3. Major Crops—1973**

Commodity	Acres harvested X 10 <sup>6</sup>	Residue, Dry Wt.		
		Tons/acre	Total X 10 <sup>6</sup>	
			Minimum	Maximum
Corn	62	2-3	124	186
Hay	62	3-7	186	432
Soybeans	56	1-2	56	112
Wheat	54	1-2	54	108
Sorghum	16	2-3	32	48
Oats	14	1-2	14	28
Cotton	12	1-2	12	24
Barley	11	1-2	11	22
Total	287		303*	528

\* Total yields do not include hay crop.  
Reprinted from Sloneker, ref. 19.

**Table 4. Minor Crops—1973**

Commodity	Acres harvested X 10 <sup>6</sup>	Residue, Dry Wt.		
		Tons/acre	Total X 10 <sup>6</sup>	
			Minimum	Maximum
Vegetables	3.3	1-2	3.3	6.6
Fruit	3.1	1	3.1	3.1
Rice	2.2	1-2	2.2	4.4
Flax	1.8	1	1.8	1.8
Peanuts	1.5	1-2	1.5	3.0
Sugar beets	1.2	1-2	1.2	2.4
Sugar cane	1.1	6-10	6.6	11.0
Rye	1.0	1-2	1.0	2.0
Total	15.2		20.7	34.2

Reprinted from Sloneker, ref. 19.

**Table 5**

**Analyses of Corn Wet-Milling Waste Feed Influent and Effluent for Continuous Digestion by *Gliocladium deliquescens***

Test Condition	Waste Feed* mg/l	Treated Effluent mg/l	Percent Reduction
Total solids	9640	3520	63
Total volatiles	6010	520	92
Total ash	3630	3000	18
COD	6200	545	91
BOD <sub>5</sub>	5600	128	98
Carbohydrate	4436	310	93
Organic acids	580	50	92
Protein	1030	42	96
Ammonia—N	88	2.7	97
Total phosphate	17	1.0	94
Fungal mass (inoculum)	68	3500	—

\* Feed includes 0.25% heavy corn steep liquor (equivalent to 1.0% 'light' CSL used previously). pH of fermentation was 4.2.  
Reprinted from B. Church annual report, ref. 4.

BOD of 32-60 g/l, depending upon the process. Whey is an excellent nutrient source for microbe development, containing 5% lactose, 1% protein, 0.3% fat, and 0.6% asn.

#### Fruit and vegetables

Processing plant wastes for different fruits and vegetables vary in character and quantity. The effluents consist primarily of

Table 6. Grain Processing Waste Characteristics" \*

Parameter	Corn Wet Milling (Average)	Corn Dry Milling (Average)
Flow	18.3	—
BOD	7.4	1.14
COD	14.8	2.69
Suspended solids	3.8	1.62

\* Corn wet milling— to produce corn syrup or starch.

Corn dry milling— to produce meal and flour; water usage limited to washing, tempering, and cooling.

\* EPA, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Grain Processing Segment of the Grain Mills Point Source Category", EPA 440/1-74-028a, 1974, Washington, DC.

\* Flow = 1/kkg grain processed; BOD and suspended solids = kg/kkg grain processed.

Table 7. Continuous Culture Digestion of Corn Wastes by a Strain of *Trichoderma viride*

Test	Milligrams per Litre			Reduction (%)
	Feed	Feed Addition	Effluent	
COD	5200		196	96.2
BOD <sub>5</sub>	3976		35	99.2
Carbohydrate (total)	3500		64	98.2
Protein (Folin)	200		7.5	96.0
Nitrogen (Kjeldahl)	96	110*	2.4	98.8
Phosphate (total soluble)	32	16.5	0.15	99.6
Sulphate	120	280	210	48.0
Chloride	784		55	93.9
Mycelial weight	0		2200	
Solids in feed	4000			
Solids in effluent			760	81.0
Ash	980		510	52.0

\* Ammonium sulphate added as nitrogen source to give mycelium of high protein content. Reprinted from Church et al. (ref. 5).

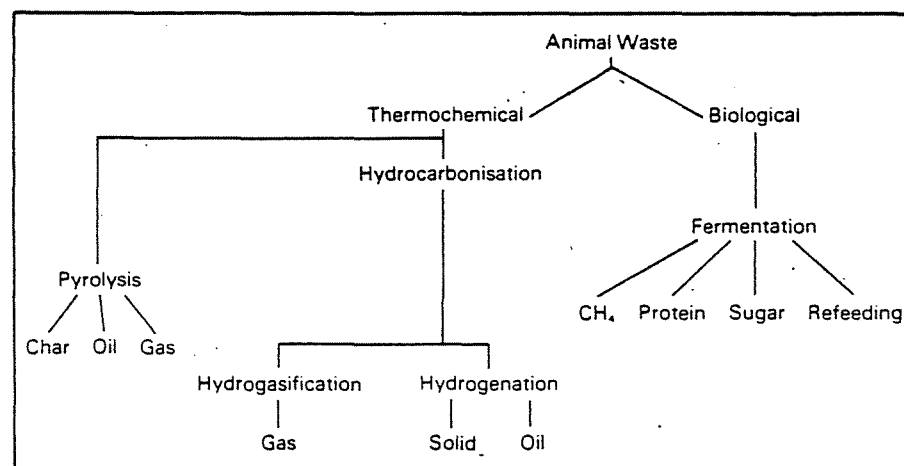


Figure 2. Process alternatives for the generation of fuels from animal waste.

carbohydrates, starches and sugars, pectins, vitamins, and plant cell wall residues. One must consider how the various types of processing operations affect availability and type of residues. Table 9 depicts some typical fruit and vegetable residues and characteristics based upon the quantity of material processed or quantity of material produced. Supply problems, due to various geographical locations and seasons, hinder large-scale utilisation of these residues for fermentation purposes. Waste waters and peels from potato processing also serve as an

excellent starch source, but seasonal production hinders utilisation of residues. The most promising end uses for potatoes involve recovery of starch for cattle feeding and for production of sugar, single cell protein, and biogas.

The enormous amounts of spoiled, damaged, and culled fruits and vegetables are excellent sources of carbohydrate material. These materials typically are good substrates for the growth of many fungi, especially on acid fruits. However, a real problem exists in that these materials are

Table 8. Manure Production in the United States

Animal*	Dry Measure X 10 <sup>6</sup> Metric Tons	Percent of Total
Cattle	195	82
Swine	22.4	9.4
Horses	12.6	5.3
Poultry	4.59	1.9
Sheep	2.89	1.2
All	237 <sup>a</sup>	100

\* Animal population numbers were obtained from reference (24) and quantity of manure produced per animal was obtained from reference (3).

<sup>a</sup> Wet weight = 1.5 X 10<sup>6</sup> metric tons at 16.1% dry matter.

<sup>c</sup> Reference from Jewell (9).

seasonal, so that a microbial process cannot be run the year round because large amounts are available only at certain times. The dollar value of this waste material is quite large. Sparks<sup>22</sup> estimated that as much as 14 billion dollars worth of food is lost during the marketing process and that 2.5 billion dollars of the loss occurs in retail stores. For example, at the time of harvest, 6% of the potato tubers were culled or had serious bruises; by the time the potatoes reached storage, this had risen to over 14%. Market losses for fruit are much higher. Sparks presents market losses of various fruits in the Chicago area for the years 1966-1969 from 6 to 41%.

These losses include microbial, nonmicrobial, and physical damage at the wholesale, retail, and consumer levels.

A typical example of the use of fruits in fermentation and of the special byproducts of the citrus industry in Israel, and how they are disposed of, is described by Mateles<sup>14</sup>. Citrus is processed in four to eight different locations in Israel, and the peels are dried for animal feed. In processing, the peels are ground with lime and pressed to expel the juice (known as "citrus peel juice"). The dried peel powder is used as animal feed. Fermentation studies have shown that 100 litres of citrus peel juice fermented with *Candida tropicalis* yield about 4kg of yeast. If all the citrus peel juice were fermented, Mateles<sup>14</sup> states that about 2,000 tons of single cell protein could be produced annually. The limitations of this process are that the citrus material is available for only about 100-150 days per year and cannot be stored or transported economically.

Another good example of the use of a plant waste material as a fermentation substrate is the extensive research and development conducted by Tate and Lyle Limited, Reading, England, on the utilisation of the pods of the carob tree, *Ceratonia siliqua* L. The beans from the pod are used commercially in producing a galactomannan polysaccharide. The remainder of the pod is useless. During the summer, these pods contain a sugar content as high as 50% or more; 60% of the sugar is sucrose but also contains glucose and fructose (30%), and the other 10% represented by other sugars. However, the pods have a low protein level (4%) and high tannin levels (up to 1.5% dry

weight) which interfere with the digestive enzymes of ruminants and pigs. The process developed at Tate and Lyle is described by Imrie and Vlitos<sup>8</sup>. A simple extraction of sugars is made and, after addition of simple inorganic nutrients, the medium is sterilised and inoculated with an *Aspergillus niger*. The *A. niger* selected had a generation time of 4-5 hours, produced a tannase, had a good mycelial protein content, was nontoxic, and had a high carbohydrate conversion efficiency. Although this process was designed for a village process, we understand a production facility is now operating and using the beans, but with a higher technology and a different microorganism.

Considerable quantities of various residues are produced as byproducts of oils and oilseeds. The major residues are generated from the harvesting and processing of groundnuts, cottonseed, palm oil, and olive oil. The shells of numerous oilseeds could be used as a resource in the production of activated carbon. The most promising uses for these residues include direct animal feeding, lignin recovery, pentosans, cellulose (furfural, xylitol), fertilisers for arid lands, and other fibre-based materials. Palm oil may be an important source of energy to make a utilisation plant self sufficient. The main constraint in the effective use of these residues is the difficulty of collection and transport to a processing location. Although this commodity group represents an enormous number of residues, it also represents greater distribution and volume problems.

Rolz<sup>17</sup> has discussed the available waste material from processing cane and coffee as potential sources of single cell protein. Beginning with 100kg of coffee, the byproducts potentially usable for fermentation to single cell protein are depicted in a typical coffee-processing operation in Central America (Figure 3). Current operations involve burning the hulls, which consist of cellulose and related polysaccharides. The dried hulls containing alkaloids are used as a mulch in the coffee fields. The water used in depulping and washing is discarded into rivers, causing pollution problems. The composition of these byproducts is listed in Table 10<sup>17</sup>.

Rolz also discusses the utilisation of sugarcane in Central America, namely, molasses, filler mud, and bagasse. Large amounts of each accumulate at sugar-producing plants in Central America (73 central mills) and elsewhere in the Tropics of developing countries.

#### Paper mill wastes

For many years, liquid paper mill wastes have been fermented to produce Torula yeasts using *Candida utilis*. Other solids in wood milling are used in making other products, especially for the building industry. The Pekilo process for using spent sulphite liquor is typical of the industry, but this process also may be used for waste liquor from sugar and potato industries. Romantschuk<sup>18</sup> has described the Finnish process in detail. The modified outline of this continuous process is shown in Figure 4 and results in protein, sulphite, and material burnt for energy.

The Pekilo process was developed by the Situ group made up of a number of co-operating Finnish companies. Spent sulphite

Table 9. Raw Waste Loads\* for the Fruit and Vegetable Processing Industry

Category	Flow gallons/ton	BOD lb/ton	Total Suspended lb/ton solids
<b>Fruit</b>			
Apple processing	690	4.1	0.6
Apple products except juice	1290	12.8	1.6
Citrus all products	2420	6.4	2.6
Olives	9160	87	15
Pickles fresh packed	2050	19	4
Tomatoes	2150	8	12
peeled products	1130	3	5
<b>Vegetables</b>			
Asparagus	16,530	4.2	6.9
Beets	1210	39.4	7.9
Carrots	2910	39.0	24
Corn canned	1070	28.8	13.4
frozen	3190	40.4	11.2
Lima beans	6510	27.8	20.7
Peas canned	4720	44.2	10.8
frozen	3480	36.6	9.8
White potatoes	1990	54.6	74.8

\* The raw waste load is in terms of the quantity of wastewater parameter per ton of raw material processed for fruits and vegetables. Raw waste loads are those generated from canning processing.

Table 10. Chemical Composition of Coffee Byproducts\*

	Solid Byproducts % Dry Basis		Liquid By products	
	Pulp	Hulls	Water Used for Depulping	Water Used for Washing
Fat	1-2	0.5		
Protein	4-12	1-2	Total solid	5-7
Cellulose	12-20	50	Total COD	3-10
Hemicellulose	—	38		
Pectin	6	—		
Total sugars	14	—		

\* From Rolz, 1975 (17).

liquors are made up of monosaccharides, polysaccharides, carbohydrate derivatives, and acetic acid. In a papermill of 100-thousand-ton capacity, about 10-15 thousand tons of protein may be produced annually. The chemical composition of spent spruce sulfite liquor, as given by Romantschuk<sup>18</sup>, is shown in Table 11.

In the process shown in Figure 4, the substrate is first stripped of sulphur dioxide, cooled, and fed as sterile media from the stripping operation directly into the fermenter. The chemicals added are ammonia, potassium, and phosphorus. The substrate is continuously fermented and has a retention time of 4.5-5 hours. A protein plant, not subsidised by the government, was built in Finland to use this process to produce animal feed. The dried product contains 55-60% protein of which 87% is digestible; contains vitamins and minerals; and is intended as a feed supplement. Similar processes are in use in the United States, Russia, and probably in other countries using sulphite liquor to produce protein from yeast.

Table 11  
Chemical Composition of Organic Dry Substance in a Spent Spruce Sulphite Liquor\*

	%
Lignosulphonic acids	43
Hemilignin compounds	12
Incompletely hydrolysed hemicellulose compounds and uronic acids	7
<b>Monosaccharides</b>	
D-Glucose	2.6
D-Xylose	4.6
D-Mannose	11.0
D-Galactose	2.6
L-Arabinose	0.9
Acetic acid	6
Aldonic acids and substances not investigated	10

\* From Romantschuk 1975 (18).

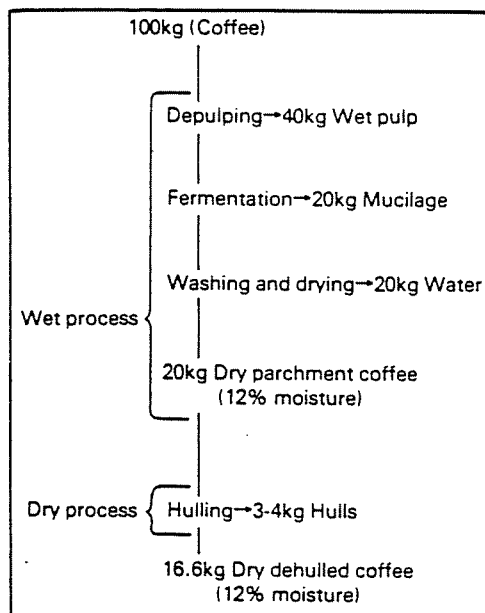


Figure 3. Typical coffee processing operation in Central America.

#### Selection of microorganisms for residue utilisation

In selecting the microorganisms to be used in converting a waste material into a useful product by fermentation, there are two directions to go. Fermentation conditions can be set in such a manner that one or two species of organisms are selected to carry out the fermentation. Methane is produced from non-sterile media using high temperatures and anaerobic conditions with suitable substrate.

The criteria for selection of a micro-organism for use with a waste material, to produce proteins and chemical endproducts, can be summarised as follows:

1. High protein content of cells.
2. Rapid cell doubling time.
3. High substrate conversion efficiency.
4. Supplementary nutrients to medium, none, or simple and cheap.
5. Nontoxic, nonpathogenic.
6. Genetically stable.
7. Produces useful secondary product(s).
8. Selective advantage in medium.
9. Ease of biomass recovery from liquid medium.

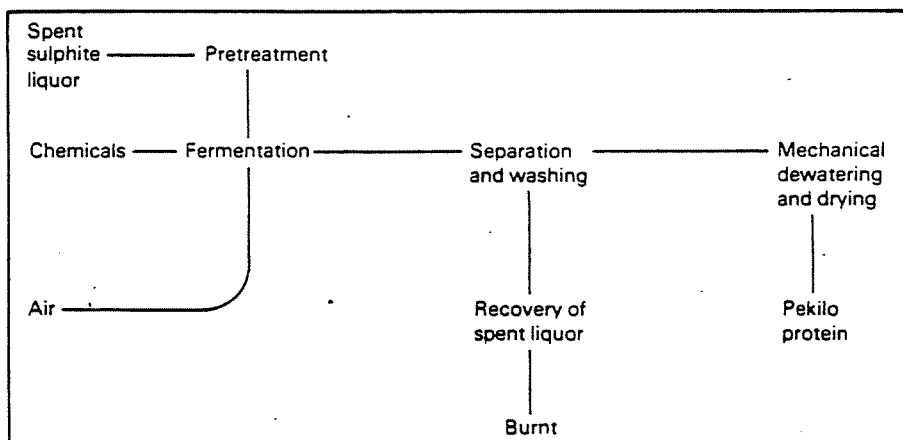


Figure 4. Utilisation of spent sulphite liquor.

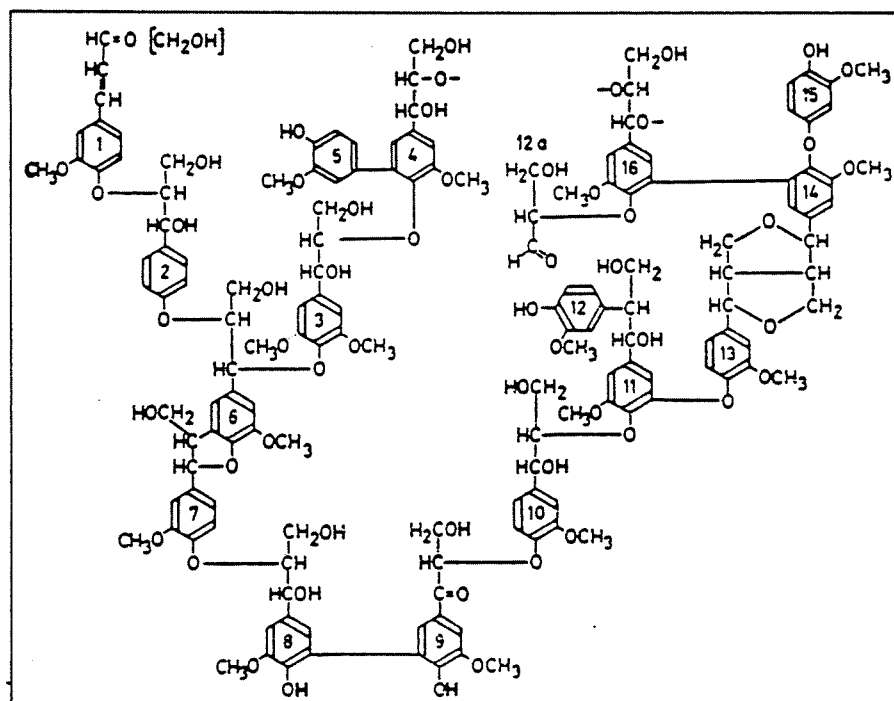


Figure 5. Structure of lignin.

10. Acceptable as feed.
11. High nutritive value.

#### Composition

The major components in agricultural residues are the structural cell-wall polysaccharides, primarily cellulose and hemicellulose. The latter two are the most plentiful renewable resource produced by most green plants. These carbohydrates constitute 45-70% of the weight of a dried plant, varying according to age and maturity of plant at harvest. Pure cellulose, such as cotton fibre, is rarely found in nature, but rather in combination with other polymers such as lignin, pectin, and hemicellulose. Lignin comprises from 3-15% of the dried plant residue. This material is the structural glue that binds filaments of cellulose into fibres for cell integrity and rigidity. Lignin is found in all fibrous plants, and generally increases with age of the plant. Cellulose increases in ageing fibrous plants with a decrease in soluble sugars and an increase in lignin. Lignin is a three-dimensional polymer formed by the condensation of cinnamyl alcohol monomers depicted in Figure 5. All possible combinations of the cinnamyl radicals can occur, resulting in various types of bonding. The exact linkage and structure of the lignin-cellulose complex is of considerable debate. There is considerable intermolecular bonding between the uronic acids of hemicellulose and lignin phenolic groups. Lignin apparently forms a three-dimensional net around the cellulose fibres. It is in this fashion that the complex cellulose is rendered unavailable to subsequent enzyme degradation. It is also in this complex area of lignin-cellulose interaction where the ultimate utility of agro-residues has its future. Chemical and/or biological modification of this lignocellulosic complex would result in increased digestibility of the agro-residue, increased hydrolysis rates, and saccharification. Continued research in the area of utilising lignocellulosics is of paramount importance to the future of these negative-value carbohydrate wastes. Table 12 depicts the relative composition of some important US agro-residues.

#### Technologies for utilisation of residues

Residue utilisation must be considered with optimism due to the large quantities of wastes and byproducts available, the need to better utilise existing resources, and the successful processes that have been attained. Successful residue utilisation must include the following changes in approach: (a) residues as resources, not wastes; (b) incentives to change philosophy; (c) evaluation of socio-economic aspects; (d) use of appropriate technology; (e) beneficial use; (f) proper market; and (g) better usage of raw materials. Promising technologies are needed for the utilisation of agricultural and agro-industrial residues. Some of the most promising and successful technological processes for the utilisation of agro-wastes are described in Table 13.

In conclusion, one can readily see the prospective value of agricultural raw materials available for the production of chemicals. The plant residues and wastes become an excellent resource as a feedstock for chemical production from starch and cellulose—sugar (fermentable). Figure 6 depicts a general schematic for chemical production from agro-commodity wastes.

Table 12. Composition of Agriculture Residues

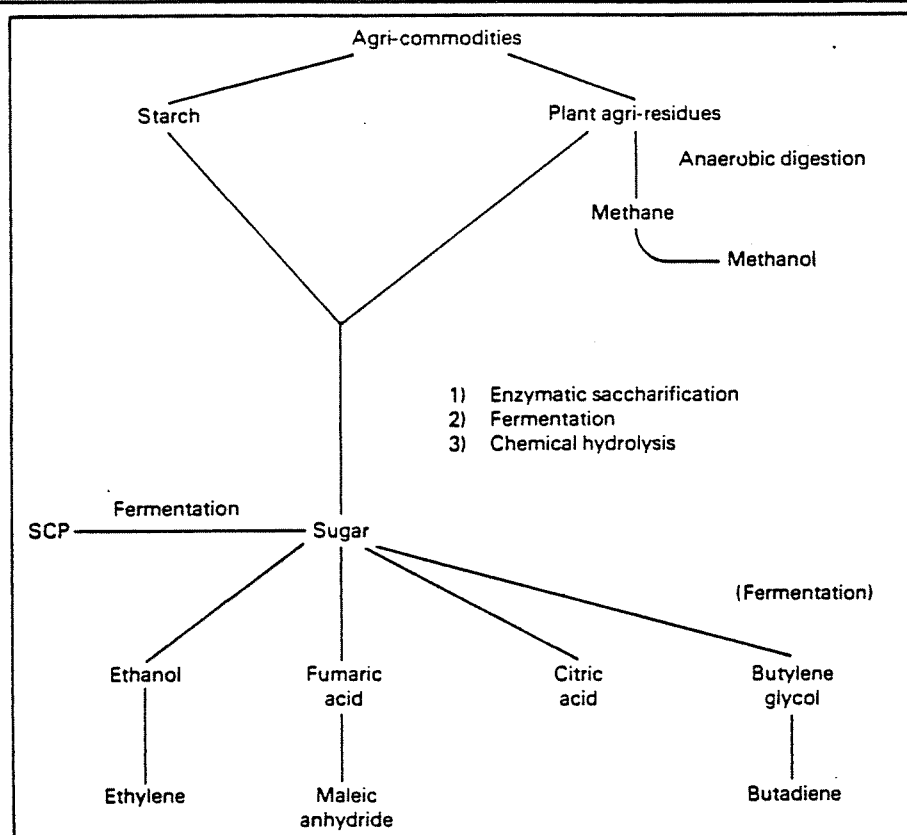
	Arabinose	Xylose	Mannose	Galactose	Glucose	Total	Cellulose	Lignin <sup>a</sup> (%)	Protein <sup>a</sup> (%)	TDN <sup>a</sup> Ruminant
<b>Plant Residue</b>										
Cornstalks	1.9	15.5	0.6	1.1	37.7	56.8	29.3	3.1	5.5	60
Flax straw	2.1	10.6	1.3	2.2	34.7	50.9	34.5		7.2	41
Kenaf stalks	1.5	12.8	1.6	1.3	41.4	58.6	41.9	12.3	4.6	
Soybean straw	0.7	13.3	1.7	1.2	43.7	60.6	41.4		5.5	42
Sunflower stalks	1.4	19	1.35	0.05	39.4	43.8	35.1		2.1	45
Sweet clover hay	3.2	7.2	1.2	1.7	31.1	44.4	29.8		24.7	63
Wheat straw	6.2	21.0	0.3	0.6	41.1	69.2	40.0	13.6	3.6	48
Cattle waste	0.38	0.77	0.73	0.97	24.4	27.2	16.4	6.5	10.1	—
Swine waste	0.43	0.83	0.98	1.27	25.5	29.8	16.6	1.6	15.1	—

<sup>a</sup> TDN = Total digestible nutrients.

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Figure 6. Generation of chemical feedstocks via bioconversion of agricultural materials.

Table 13. Technologies Available for Utilisation of Agro-Industrial and Agricultural Wastes

Residue Substrate	Process	Product	Operational <sup>a</sup>	
			Advantages	Disadvantages
Animal waste	Microbial	CH <sub>4</sub> , feed supplement	Cheap resource produces energy available reduce pollution	High initial investment
Animal waste	Microbial	Cattle refeeding, single cell protein	Cheap resource centrally located	
Sugarcane bagasse	Microbial	Single cell protein	Surplus availability technology available	
Dairy whey	Microbial	Single cell protein, alcohol	Reduce pollution surplus availability	High salt content transportation
Cereal process waste	Microbial	Single cell protein	Reduce BOD and COD	
Cellulosic pulps	Enzymatic (saccharification)	Sugar		
Hemicellulosics (xylans)	Enzymatic	Xylose		Expensive
Starch waste	Microbial	Alcohol	Cheap resource	
Wood pulp sulphite liquor	Microbial	Single cell protein	Surplus availability	

<sup>a</sup> Items listed on basis of economics, availability, pollutant, and source.

# Availability and Utilisation of Agricultural and Agro-Industrial Wastes

*continued from page 7.*

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